Static Requirement and Type's Complexity in the Diagnostics Phase

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Abstract: The preservation of a historical building, whatever its architectural and/or artistic value, is more successful when undertaken with a deep understanding of the building's history, development, materials and construction techniques. The preliminary phase of any restoration intervention must start with data acquisition regarding the characteristics and conditions of the building, including a survey of significant alterations. In a great number of cases, restorations are not respectful of the building's static efficiency, so its static requirement is weakened. In fact, a very high percentage of instances in which a restoration effort results in building damage is attributable to such modification's indifference to the structural balance of a structure, as consolidated over time. This study focuses on the restoration intervention on two trilobate pillars that separate the central space from the presbytery in the Cathedral of Matera, located in southern Italy. Through the use of sonic tests - carried out despite the complexity of the shape of the building and constructive elements that characterize these pillars — it was possible to show the effectiveness of the implemented intervention, highlighting critical points and weaknesses. The research aims to show how — despite the complexity of some structural elements of a building — in-depth knowledge of a structure's structure and history is essential to for the success of restoration interventions, which are respectful of a building's type and material peculiarities.

Key words: Structural complexity, static requirements, refurbishment interventions, diagnosis phase, conservation.

1. Introduction

The preservation of a historical building, whatever its architectural or artistic value, is more effective when based on an in-depth understanding of the building's development, materials and constructive techniques.

In fact, the protection and conservation of heritage buildings entails varied and sometimes even alarming aspects; however, they help us to identify the commonly called "*architectural emergency*". This is essentially related to the size and the great number of cases to resolve and — together — to the limited availability of usable resources and experiences. So, it's necessary to optimize in a better way the limited finances and resources allocated to restoration efforts.

Faced with a degraded monument, the renovation designer must answer three main questions: "*if*" to

perform a restoration, "*where*" to perform a restoration and "*how*" to perform a restoration.

To these questions it is possible to add another one that regarding the economic aspect: "*when*" to perform a restoration intervention [10].

In order to respond adequately to these questions, it is necessary to advance "*step by step*", through easily defined procedures: the identification of degradation, the determination of its causes, the assessment of residual safety and, finally, the appropriate intervention and definition of its execution method [8].

So the preliminary action is the research of all information about the monuments; this information is required to describe the structure and all the transformations that it has suffered; in this situation, it becomes essential to know the history of the building, from its construction until the last modification that it has undergone. In the first phase of data acquisition, the direct recognition of the building characteristics and the survey of the checked alteration, should be

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complemented by research of design documentation and of events that have affected the structure during all its life cycle [9].

2. Shape's Complexity and Static Balance

The structural and static complexity of the historical building represent the more important characteristics of each monument. In fact, in the last years, the necessity to operate interventions of masonry structural reinforcement has become increasingly urgent, stimulating both by the objective requirements related to increased degradation of the monumental buildings and by a greater interest towards conservation theory.

The restoration criteria, in fact, impose severe restrictions on the possibility to realize a different intervention types but — at the same time — stimulate the choice of the suitable solutions.

Naturally, these solutions will seek in changes to realize to the main parameters that constitute the mechanical part of the structure (i.e., the geometry, material and loads) [12].

In fact, changes, modifications, partial demolition and reconstruction are quite frequent in a building's history, especially in a monumental building. A lot of monuments, in fact, have modified its shape and its structural and functional organization in its life cycle, realizing — for example — of super elevation or addition part of construction, modifying the static distribution of the force, etc.; a very high percentage of building damages are attributable to these modifications are not always sufficiently respectful of a structural balances consolidated over the time.

These changes led to new structural stresses - not always proportionately allocated over the building structure — and very often they lead a new shape and aesthetical characteristics.

Thus, the geometry changes are surely the most effective (i.e., the increase of stiffness obtained with the increase of resistant section or by adding a constraint) [11].

The criterion for an intervention on the geometry was almost abandoned, although structurally good; the practice of complete replacement of degraded elements with other more or less “*similar*” to the original is realized very often, while frequently are offered — in parallel to existing structures — structures that are able to bear the load of the structure, in case of triggering the collapse.

It is considered, therefore, that the elaboration of a proposed consolidation intervention is essential to achieve different objectives that ensure the maximization of the monument respect.

These objectives are:

- (1) to allow maximum persistence of the original material, limiting at minimum the transformations (demolition, replacement, etc.);
- (2) to recognize the variable “*time*” as a positive sign that are able to add value to the building, which must be understood as a “*palimpsest*” on which are layered different elements;
- (3) to use objective knowledge that are closely related to the building or specific pathological situation;
- (4) to make decisions on the basis of technical assessments, supported by an in-depth knowledge and never based on historical, critical or aesthetic judgments;
- (5) to realize recognizable and reversible interventions, in order to make possible in the time control, monitoring, additional maintenance (i.e., the introduction of new technologies or systems more effectively);
- (6) to establish a correct maintenance program over time, not aimed at any replacements intervention at predetermined intervals, but based on observation of the phenomena, in order to prevent possible dangerous situations and slow down the aging process of the building.

3. The Case Study

This research focus upon the Cathedral of Matera — located in a little city in the southern part of Italy (Fig. 1),

a massive architectural structure, built at the end of the XIII century. In *Apulian Romanesque* style, it keeps its formal and architectonic connotations almost unchanged outside, even though some interventions have substantially changed the inside style. It does not show any plain deterioration signs of its static structure, but it is plain a pathology outside.

The study focuses on the analysis of the restoration intervention on two trilobate pillars (Fig. 2) that separate the central space from the presbytery.

Using sonic tests — carried out despite the complexity of the shape of building structural and constructive elements that characterizes these pillars — it is possible to show the effectiveness of the implemented intervention, highlighting its critical points and its weaknesses [1].

In fact, with the sonic tests are measured and analyzed the characteristics of propagation of elastic waves inside the walls with the aim to understand the homogeneity of the structure, the changes of material properties caused by degradation, the structural defects — such as cavities or cracks — and the magnitude of the resistance of materials [2].

This test is carried out by measuring the time and speed of the wave that passes through the wall, a mechanical impulse generated by a transmitter and picked up by a receiver [3].

The speed of an elastic waves in a homogeneous, isotropic and perfectly elastic, is linked to the dynamic elastic modulus E_d , by the following relation:

$$E_d = v^2 \cdot d \cdot \frac{(1+\nu)(1-2\nu)}{(1-\nu)}$$

in which:

E_d = dynamic modulus in Pa

v = speed of the wave in ms⁻¹

ν = Poisson modulus

d = density of the elements in kgm⁻³

The elastic wave loses energy in his propagate, and this is due to a decrease in the intensity related to the propagation law of the spherical type, while another decrease is the interface between the gap, where the

Fig. 1 The Matera Cathedral.

Fig. 2 The trilobate pillars.

energy is partly reflected and partly refracted [4, 5].

High speed — closely proportional to the elasticity modulus and to the strength of the element — and short term indicate a compact structure (i.e., single body masonry or multiple body well connected), while discontinuities, fractures, porous materials are considerably lower speed and consequently increases time.

The test was performed on the above said columns, identifying different directions (Figs. 3–5) — at different heights — in order to cover the largest part of the surface; these directions would also consider the

Fig. 3 Sonic directions of investigations carried out on the left trilobate pillar.

Fig. 4 Sonic directions of investigations carried out on the right trilobate pillar.

Fig. 5 Damage visible on the surface of the pillars.

different materials connections, related to the particular shape of the pillars. Certainly this complexity became an important element to evaluate in order to operate a correct and precise evaluation of the investigations project [7].

Tables 1–2 show, for each chosen investigation's directions, the values of average speed; in fact, they represent the average values of 12 speeds measured. In fact, were made 12 different measurements that returned 12 different values of propagation time of the wave and, consequently, 12 different values of propagation speed.

The sonic test carried out on the left pillar (Table 1) highlights the values between 1400 m/s and 1800 m/s at different levels and in the range 1.50–2.73, which usually characterize those walls not strongly degraded and presence of voids.

From the observation of results, it is possible to note that lower values are not recorded along the longest paths — such as those linking the two semi-columns or the semi-column with the pilaster — but along the shortest paths within the elliptical shape. This leads us to assume a more widespread damage, also visible on the surface of the pillars [6].

While, the investigations on the right pillar (Table 2) highlight of values between 1450 m/s and 1850 m/s at different levels and in the range 1.50–2.73, which usually characterize those walls not strongly degraded and presence of voids.

Table 1 Sonic tests results on the left trilobate pillar.

As			Bs									Es		
s(m)	t(us)	V(m/s)	s(m)	t(us)	V(m/s)							s(m)	t(us)	V(m/s)
1.57	942	1686.902	2.37	1315	1763.13							2.37	1374	1768.393
	916			1321										
	944			1317										
	921			1352										
	947			1331										
	933			1346										
	922			1343										
	909			1348										
	922			1372										
	941			1355										
	983			1362										
	919			1367										
			Gs			Hs						Ls		
			s(m)	t(us)	V(m/s)	s(m)	t(us)	V(m/s)				s(m)	t(us)	V(m/s)
			1.87	1199	1598.837	1.87	1133	1823.145				0.95	613	1434.395
				1212			1002						634	
				1172			1023						628	
				1116			1017						691	
				1147			1020						639	
				1141			1036						644	
				1173			1025						661	
				1147			1039						692	
				1176			1051						668	
				1161			1027						676	
				1192			1016						692	
				1188			1003						690	
Ms			Ns			Os			Ps			Qs		
s(m)	t(us)	V(m/s)	s(m)	t(us)	V(m/s)	s(m)	t(us)	V(m/s)	s(m)	t(us)	V(m/s)	s(m)	t(us)	V(m/s)
0.61	371	1474.142	0.58	448	1494.075	0.96	341	2785.839	0.96	391	2442.748	0.84	553	1372.998
	407			408			336			393			531	
	400			415			349			389			573	
	396			429			350			382			563	
	412			405			348			381			575	
	432			431			343			381			633	
	394			353			351			394			657	
	384			354			342			399			630	
	472			354			350			405			636	
	406			348			344			405			656	
	435			354			336			401			648	
	482			379			343			395			651	

Table 2 Sonic tests results on the right trilobate pillar.

Ad			Bd			Cd			Dd			Ed		
s(m)	t(us)	V(m/s)	s(m)	t(us)	V(m/s)							s(m)	t(us)	V(m/s)
1.49	886	1694.337	2.31	1572	1644.713	2.31	#DIV/01	2.31	#DIV/01	2.31	#DIV/01	2.31	1260	1828.4
	871			1287										
	855			1257										
	879			1300										
	899			1240										
	848			1243										
	894			1019										
	863			1251										
	883			1249										
	870			1271										
	894			1284										
	922			1292										
Fd			Gd			Hd			Id			Ld		
1		#DIV/01	s(m)	t(us)	V(m/s)	s(m)	t(us)	V(m/s)	1		#DIV/01	s(m)	t(us)	V(m/s)
			1082	1750.822	1037	1883.259		620		1477.541				
			1002		957		664							
			1043		970		650							
			1046		956		670							
			1011		937		654							
			1011		960		683							
			1005		945		678							
			1005		947		724							
			989		980		689							
			1037		963		701							
			1096		966		709							
	1116	967	670											
Md			Nd			Od			Pd			Qd		
s(m)	t(us)	V(m/s)	s(m)	t(us)	V(m/s)	s(m)	t(us)	V(m/s)	s(m)	t(us)	V(m/s)	s(m)	t(us)	V(m/s)
0.67	452	1459.059	0.60	444	1440.23	0.98	394	2401.372	0.98	472	2164.789	0.83	474	1442.726
	422			434			393			452			521	
	488			440			434			436			560	
	461			416			422			433			546	
	411			416			412			472			552	
	436			408			407			436			543	
	485			402			416			407			667	
	466			415			403			472			648	
	459			410			418			440			565	
	452			418			400			452			623	
	471			402			406			462			594	
	496			407			403			536			601	

Even the pillar right, by the observation of partial results show that higher values are recorded along the longer trajectories (as above said), the lowest (about 1400 m/s) along the shortest paths within the elliptical shape. This leads us to do the same considerations of the left pillar.

Sonic tests were carried out also on the stone base of the pillars using the same investigation test. The measured values are greater than 2000 m/s that indicates a good state of preservation.

The research — applied on the above described pillars — is on going also for the other structural elements of the Matera Cathedral in order to provide a complete knowledge of the monument and to develop a suitable restoration intervention.

4. Conclusions

The research aims to show how — despite the type complexity of some structural elements of a building — becomes essential an appropriate building knowledge to realize interventions that are able to operate a correct restoration intervention of a building and, at the same time, which it is respectful of its type and material peculiarities.

The study aims to realize an applicative methodology more respectful of the monumental heritage, in order to avoid a simple critical transposition of the calculation models in the recovery interventions.

This research can also contribute to increment the typology of the tests to carry out on the masonry; in fact, in relation to all the problems of tests and investigations (first of all the geometrical complexity), it is not necessary to have only one kind of survey, but an organic plan that consider in particular way the shape and the morphology of the investigated element, in order to have a more possible complete cognitive frame. Only in this way it is possible to interpret the real phenomena and give the necessary parameters to realize a correct intervention.

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